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Properties of cement mortars modified with ceramic waste fillers

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Abstract

The paper presents the results of an experimental program intended to assess the potential of sanitary ceramic waste utilization as aggregates in cement-based mortars. Their influence was evaluated with respect to workability (consistency, plasticity, pores volume), mechanical properties (compressive and flexural strength) and freeze-thaw resistance. The results showed that partial replacement of fine aggregate with sanitary ceramic fillers up to 20% of cement by weight improves compressive and flexural strength and reduces shrinkage. The test results were discussed in the lights of the literature data on influence of ceramic waste on properties of fresh and hardened concretes.

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Keywords: Sanitary ceramic waste; Fillers, Mortars; Properties

1. Introduction

Sustainable development is nowadays the main topic around the world in all areas of human activity. One of areas that consume large quantities of natural resources is civil engineering. For example, the yearly consumption of aggregates in Poland equals 4-4.5 ton/person and result in exploitation of 3 milliard tons of non-renewable natural resources per year, with an average annual increase of 7 % [1]. Taking into consideration this fact, the search for alternate mortar and concrete components, preferably made from recycled and waste materials, becomes

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crucial. Still, the basic condition for the implementation of such innovative approaches is the assurance that it will not result in any significant reduction in the quality of the structures and elements built with these products.

The use of ceramic waste in cement composite manufacturing fits very well into sustainable development strategy. There are some publications addressing the potential of different types of ceramic waste as active additives to Portland cement-based materials [2-4], most of them dealing with their influence on the properties of mortars and concretes when used in replacement of natural aggregates [5-8]. Medina et al. examined the properties of concretes that incorporate 4/12.5-mm crushed sanitary ceramic in partial replacement of natural coarse aggregate [9]. Results of their studies revealed that incorporation of sanitary ceramic aggregates up to 25% improves compressive and tensile splitting strengths. Authors also demonstrated that the ceramic particles do not interfere with cement hydration. Moreover internal transition zone between cement paste and recycled ceramic aggregate is more compact and less porous in comparison with that found at the surface of natural aggregates, which may improve the resistance to aggressive agents. Furthermore, Medina et al. studied the permeability of O_2 and CO_2 in concretes where aggregates were replaced by 20 and 25% of 4/12.5 mm crushed ceramic waste particles [10]. The results indicated that gas permeation in both the reference and modified concretes proceeds at comparable level, regardless of the ceramic filler content. The depth of penetration of water under pressure also did not change within the investigated range of natural aggregate substitution and in relation to reference concrete. However, the volume of capillary pores in concrete was found to rise, causing increased sorptivity [11].

Halicka et al. also carried out research on the concrete incorporating ceramic waste [12, 13]. They replaced the natural aggregates (coarse only?) with crushed ceramic aggregates prepared from postproduction sanitary ceramic waste supplied by a Polish manufacturer. The ceramic aggregate used in that study had a 0/8 mm grading. The density values were similar to those of natural aggregate (2.64 and 2.36 respectively), while the absorption was found to be slightly higher (1.53%). Author reveled that concrete with sanitary ceramic aggregate would have initial cohesion. Consistency of designed mixtures examined by slump cone test were significantly different. Halicka et al. observed that slump of modified mix was more than four times lower in comparison with traditional concrete with natural aggregates, which are characterized by smaller water absorption [13]. The abrasion resistance, determined by direct measurements of specimen height changes, was greater in case of ceramic waste concrete. The same trend was observed for compressive strength, tensile splitting strength and resistance to high temperature.

2. Experimental program

High early strength Portland cement CEM I 42.5R (conforming to EN 197-1), CEN reference sand (conforming to EN 196-1), sanitary ceramic filler and pipeline water were chosen to carry out the investigation. The ceramic filler used in the experiments was obtained by crushing and grinding waste ceramic (see Fig.1) supplied by a Polish manufacture of sanitaryware. With a final maximum particle size of 0.05 mm (Fig. 2), they were considerably finer than the CEN reference sand, in which according to PN-EN 196-1 only 2% of particles could pass through a sieve with a square mesh 0.08 mm. The measured density (2.48) was found to be similar to that of ceramic additives used in concrete by Medina et al. [9] and Halicka et al. [13].

Table 1. Composition of designed mortars.

Type and symbol of mortar		Mortar composition [g]			
		Cement	Sand	Ceramic filler	Water
Reference mortar	M0	450.00	1350.00	0.00	225.00
Mortar with ceramic filler (10% of cement mass)	M10	450.00	1301.82	45.00	225.00
Mortar with ceramic filler (15% of cement mass)	M15	450.00	1277.73	67.50	225.00
Mortar with ceramic filler (20% of cement mass)	M20	450.00	1253.64	90.00	225.00

In the present study, four mixtures were produced to evaluate the influence of waste sanitary ceramic fillers on mortar properties: a reference mortar formulated in accordance with EN 196-1 (M0) and three mortars containing respectively 10, 15 and 20% of ceramic fillers by weight of cement in replacement of natural aggregates (M10, M15 and M20). Mortars mixes as well as 4x4x16 cm prisms (3 for every batch) were prepared in accordance with European Standard EN 196-1.

Fig. 1. Raw ceramic waste was first broken with a hammer into 50–150 mm fragments, then crushed down to 30 mm particles, and finally ground.

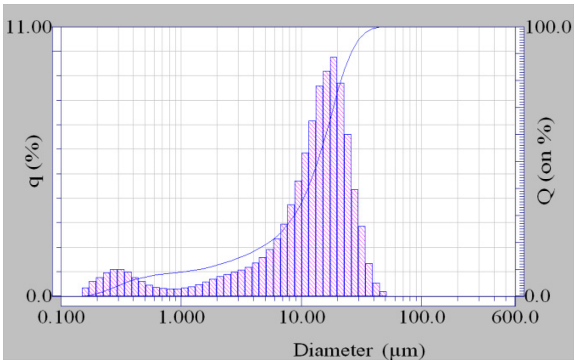

Fig. 2. Particle size distribution of ground sanitary ceramic.

3. Results and discussion

3.1. Properties of fresh mortars

Properties of fresh mortars were studied in accordance with Polish Standard PN-85/B04500. The investigation was focused on consistency (immersion of slump cone method), plasticity (flow test), workability retention, and air content.

In Tables 2 and 3, it can be seen, that the highest liquid consistency was achieved for the reference mortar. The test data indicate that incorporation of an increasing amount of ceramic filler results in a lower mortar consistency and plasticity. For the reference mortar (M0), the difference in depth of slump cone immersion recorded from the time of mixing to 60 min. was equal 3.0 cm (max. standard permissible difference for further research), while the corresponding change in mean flow diameter was equal to 3.35 cm. Therefore, for the M0 mortar, the time of workability retention was assumed to be of one hour. The consistency and plasticity test results show that as the ceramic filler content in mortar increased the time of workability retention increased, too. This can clearly be attributed to the larger water absorption of sanitary ceramic filler, compared to that of the CEN reference sand. The latter is coarser and as a consequence, has a smaller specific surface area.

Table 2. Consistency and workability retention.

Mortar	Consistency measurements [cm]				
	After mixing	After 30 min.		After 60 min.	
	Mean immersion	Mean immersion	Difference	Mean immersion	Difference
M0	5.90	3.80	2.10	2.90	3.00
M10	5.53	4.35	1.18	2.60	2.93
M15	4.30	3.25	1.05	3.00	1.30
M20	3.47	2.35	1.12	2.26	1.21

Table 3. Plasticity and workability retention.

Mortar	Plasticity measurements [cm]				
	After mixing	After 30 min.		After 60 min.	
	Mean flow	Mean flow	Difference	Mean flow	Difference
M0	15.35	13.45	1.90	12.00	3.35
M10	13.30	12.90	0.40	11.15	2.15
M15	13.15	12.40	0.75	12.05	1.10
M20	12.80	11.15	1.65	-	-

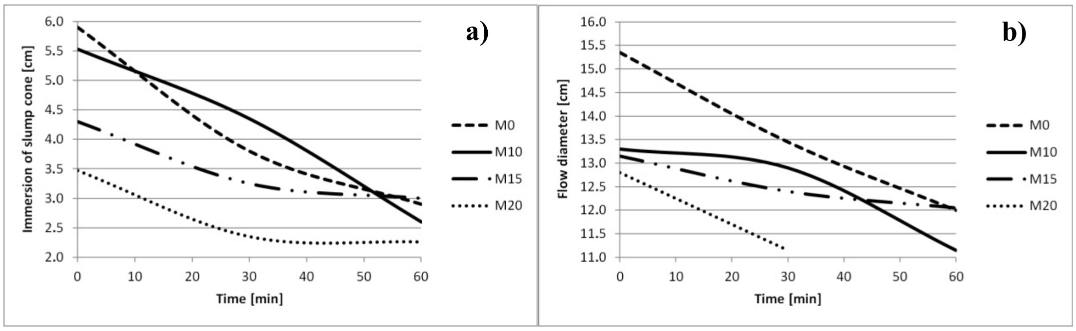

Fig. 3. Evolution of consistency (a) and plasticity (b) of fresh mortars with time.

Table 4. Air content and density of cement mortars.

Mortar	Mortars properties	
	Air content [%]	Density [kg/m^3]
M0	7.10%	2201
M10	7.40%	2184
M15	7.20%	2182
M20	6.80%	2179

These results are consistent with those reported by other investigators. Halicka et al. used sanitary ceramic waste as the only aggregate in concrete and observed reductions in slump value by over four times in comparison with that of a reference concrete [13]. Even partial substitution of coarse aggregate with 4/12.5 mm crushed ceramic aggregates required extra mixing water to achieve the desired consistency [9].

The air content values recorded for the investigated mortars were of the same order, ranging from 6.8 to 7.4% (tab. 4).

3.2. Properties of hardened mortars

As part of the experimental program, shrinkage tests, freeze-thaw resistance tests, as well as flexural and compressive strength tests (2, 7, 14, 28 and 56 d) were performed for the four investigated mortar mixtures.

A positive effect of ceramic filler addition on changes of samples volume during cement hydration can be noticed on the graph shown in Figure 4. The shrinkage recorded for the modified mortars is clearly smaller, especially within the first two weeks (40 to 60 % of the reference mixture's deformation). The reduction is observed to decrease with time (20 % at 56 d). An increase in ceramic filler content resulted in lower shrinkage, but the magnitude of the reduction also decreases over time.

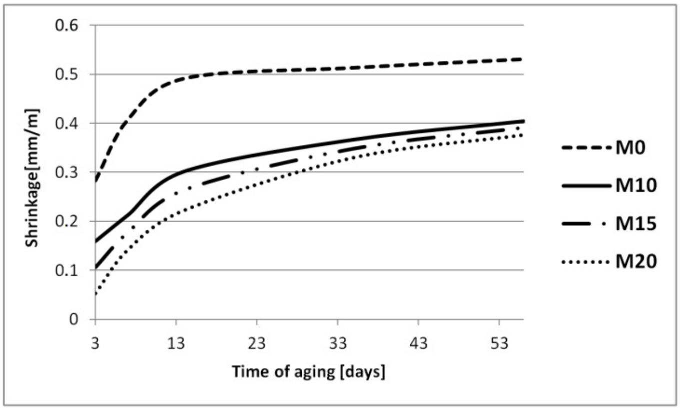

Fig. 4. Shrinkage of tested mortars.

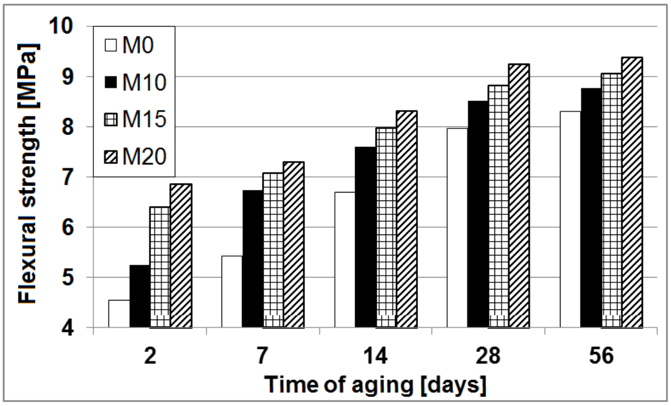

Fig. 5. Flexural strength of tested mortars.

The flexural and compressive strength test results recorded for the different tested mortars are summarized in Figures 5 and 6. Incorporation of ceramic waste aggregates led to a systematic improvement of the mechanical properties, the benefits increasing with the addition rate. At 2 d, the use of ceramic aggregates resulted in increases in flexural strength up to 50 % and compressive strength up to 42 %. Nevertheless, the influence becomes less significant with time, and after 56 days, the maximum corresponding increases were found to be equal 12 % and

11 % for flexural and compressive strength respectively. These longer-term results are consistent with those obtained by previous investigators [9], who reported a 12 % increase in the compressive strength when substituting 25 % of gravel with 4/12.5 mm crushed sanitary ceramic waste.

The freeze-thaw resistance results yielded in the present study allow to conclude that ground ceramic waste addition did not have any influence on compressive strength up to 25 cycles, the observed behavior being similar for all tested mortars. Conversely, freeze-thaw was found to affect negatively the flexural strength of all tested mortars, the reduction increasing with the ceramic waste content (reduction ranging from 21.6 % for M0 to 28.7 % for M20). Corresponding increases in mass after freeze-thaw cycles ranging from 0.61 to 0.82% were recorded.

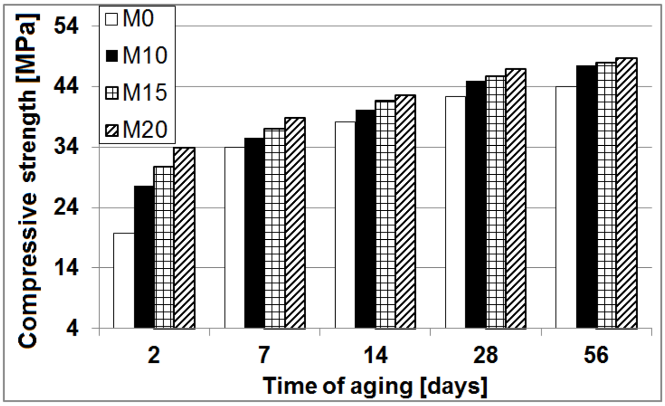

Fig. 6. Compressive strength of tested mortars.

4. Conclusions

The paper presents the results of a study devoted to the use of ceramic sanitary ware waste as aggregates in Portland cement mortars. The incorporation of 10-20% (by weight of cement) of sanitary ceramic filler in the investigated mortar mixtures caused a rise in water demand to achieve given consistency and plasticity characteristics, but a longer duration of workability retention. Besides, it resulted in significant increases in flexural and compressive strength and lower shrinkage. Overall, the results obtained in the present study are consistent with those reported previously for similar waste ceramic aggregates. It tends to confirm the possibility of using ground sanitary ceramic waste as an effective filler in cement mortars (and eventually concretes), with rates of addition (by weight of cement) of at least 20 %.

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